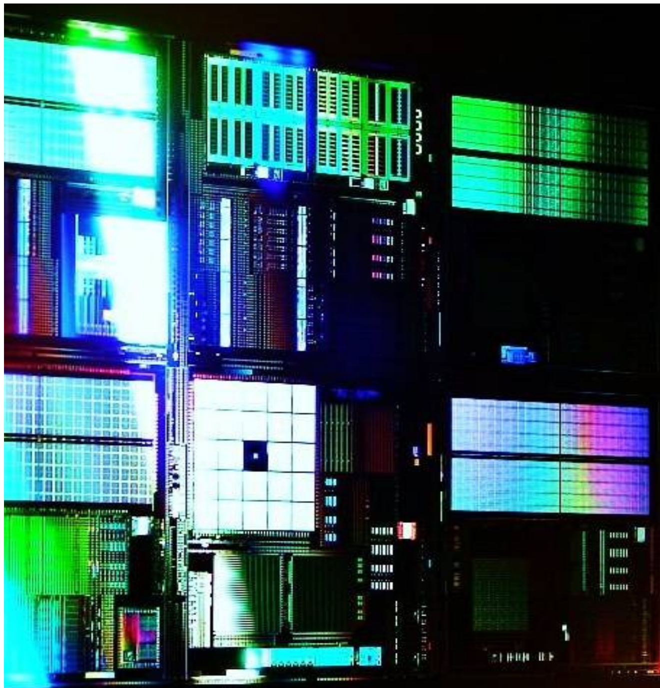

Mask Integrity

Where Lithography Begins

Understand. Align. Innovate. Develop.

Effective Solutions for In-Fab EUVL Mask Cleaning

Tobias Wähler, Sherjang Singh, Uwe Dietze
(HamaTech APE)
Rik Jonckheere, Bart Baudemprez
(IMEC)

2010 International Symposium on Extreme Ultraviolet Lithography

Topics

- Background
- Infrastructure Aspects
- EUVL Mask Cleaning
- Experimental Cleaning Results
  - Carbon Removal
  - Particle Removal
  - Surface Integrity
- Summary & Conclusions

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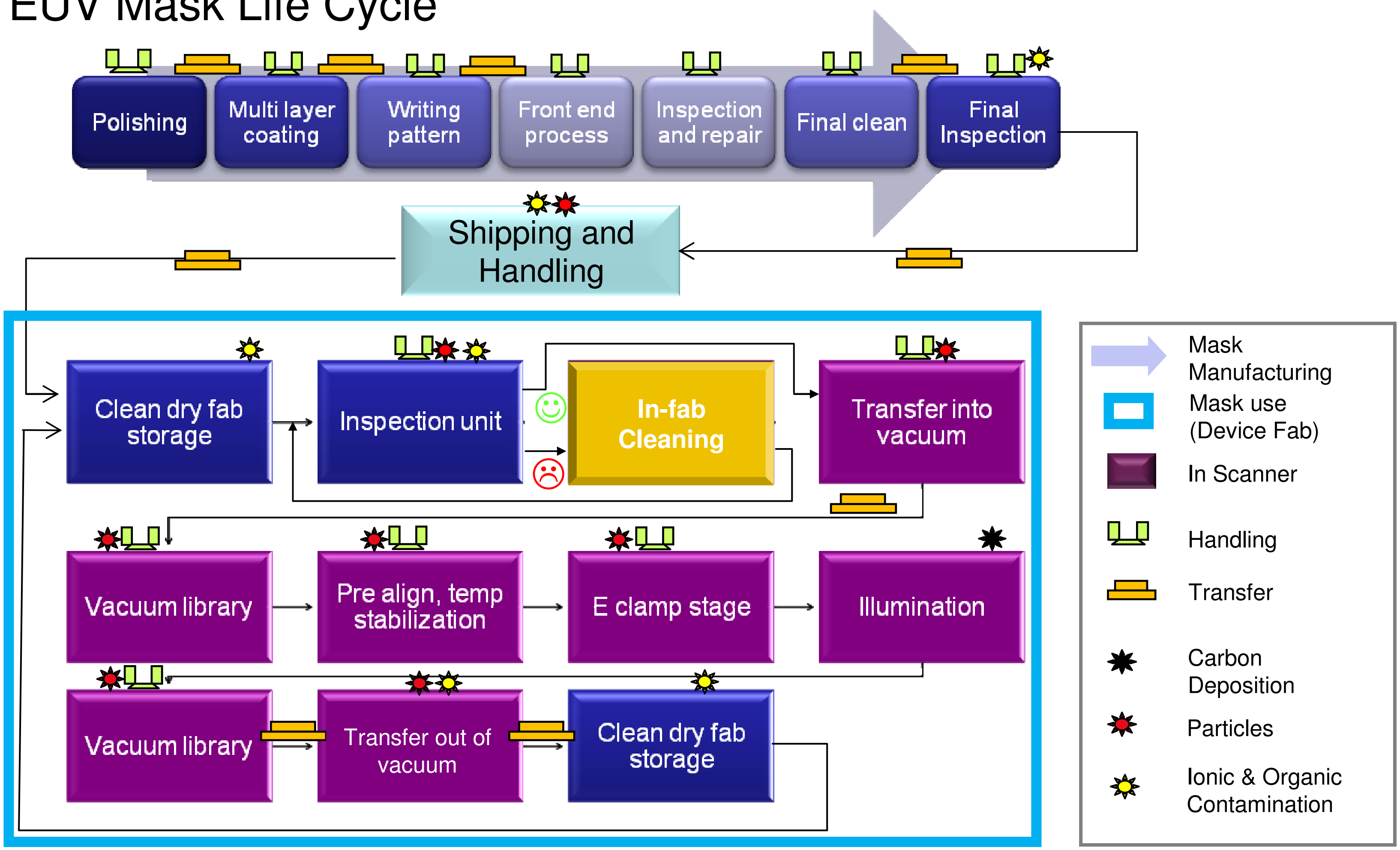
Background

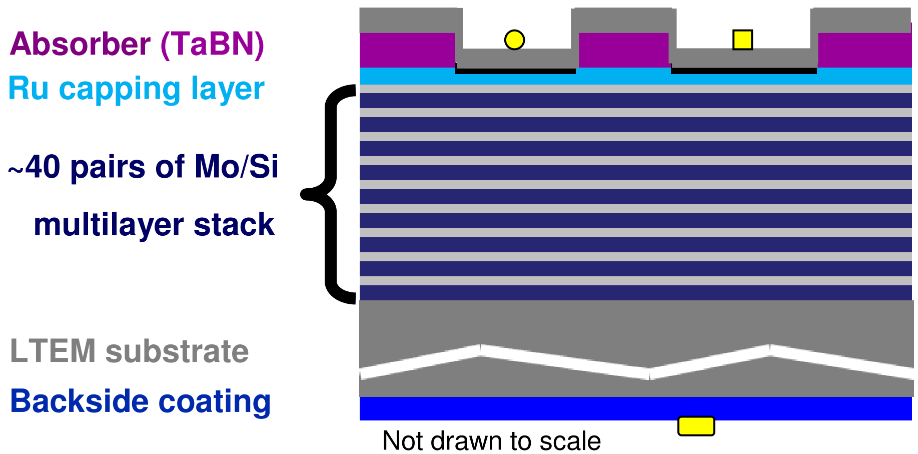
EUV Mask Life Cycle



Source: ASML, HamaTech-APE

Background

EUVL Specific Challenges



Under EUV exposure → Ru Oxidation / Carbon Growth

Handling / Storage / Use → Particles / Contamination

	EUV Reflectivity	CD shift (non-uniformity)	Litho Fidelity/Stability	Mask Life Time
Ru Oxidation	↓	↓	↓	↓
C deposition	↓	↓	↓	↓
Particles		↓	↓	

Goal → **Restore** → **Remove** → **Preserve**

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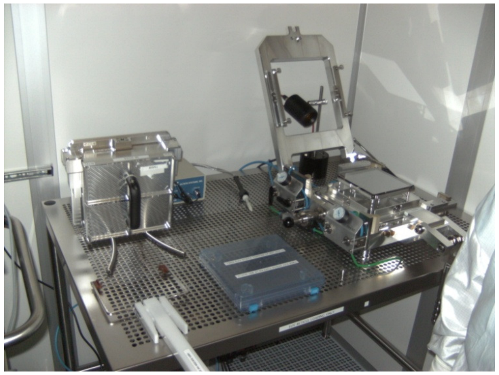
Infrastructure Aspects

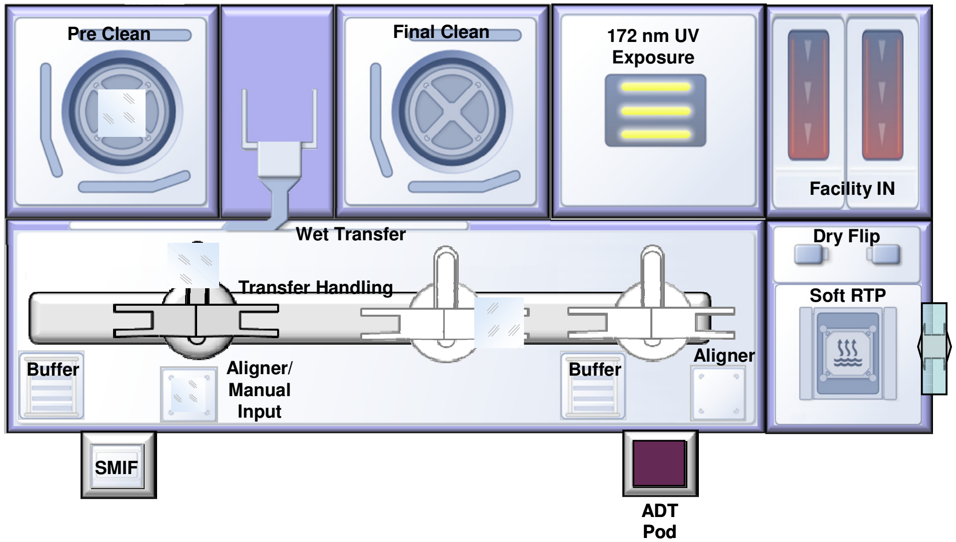
EUVL Mask Maintenance at IMEC



Phase 1:

- Receive masks in standard 193i shipping boxes
- Manual load into ADT storage box (SB) before cleaning
- Automated load into ADT SB after cleaning

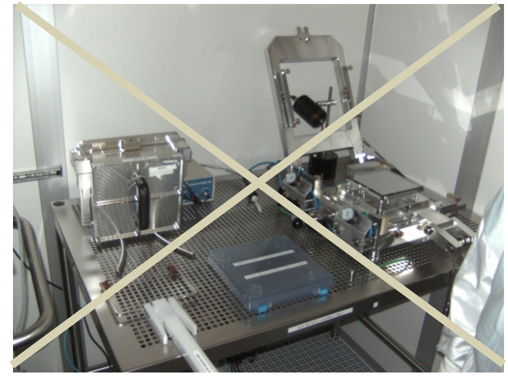
Phase 1 completed!



- *Eliminates manual handling of cleaned masks*
- *Limitation of shipping and manual handling remains*

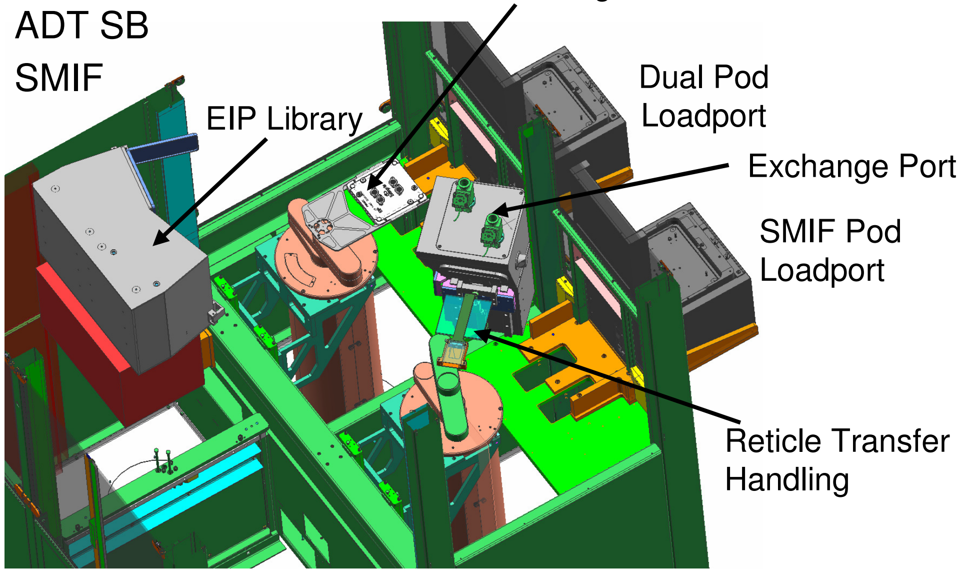
Infrastructure Aspects

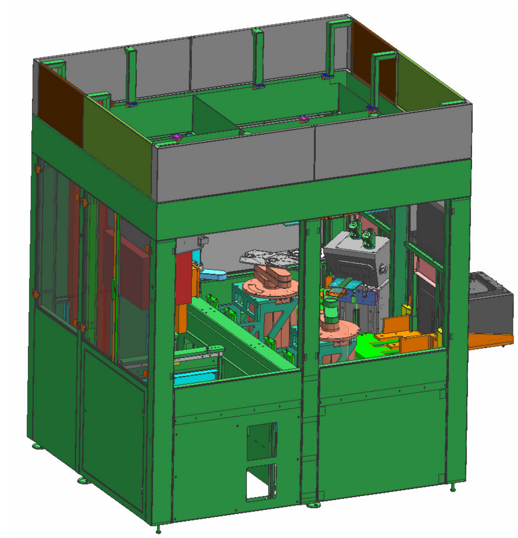
EUVL Mask Maintenance at IMEC



Phase 2:

- Totally avoid manual handling !!!
- Establish compatibility with EUV pod-in-pod
- Retain flexibility for variable input/output and transfer between:
  - Pod-in-Pod
  - ADT SB
  - SMIF

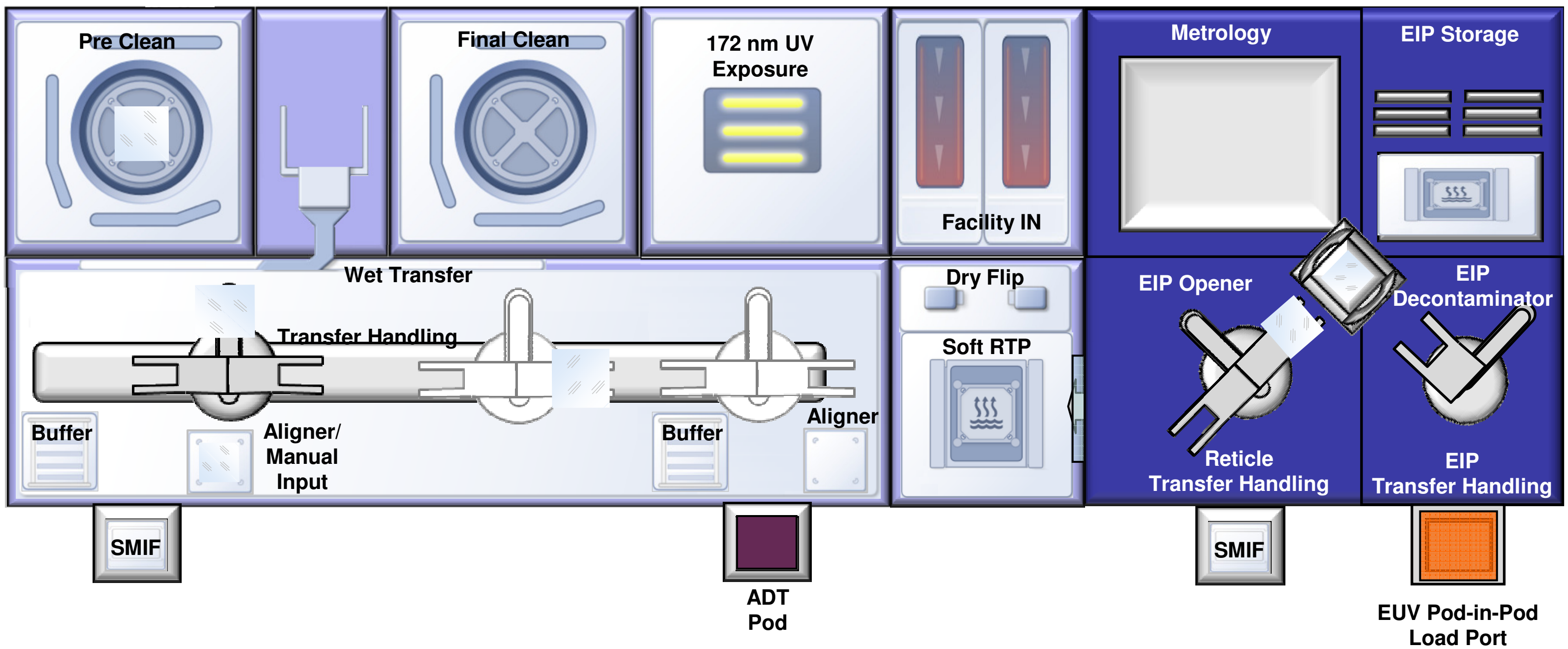


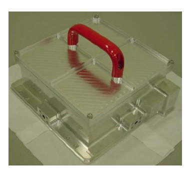


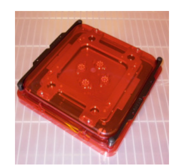
Infrastructure Aspects

EUVL Mask Maintenance at IMEC

Phase 1 (completed) Phase 2







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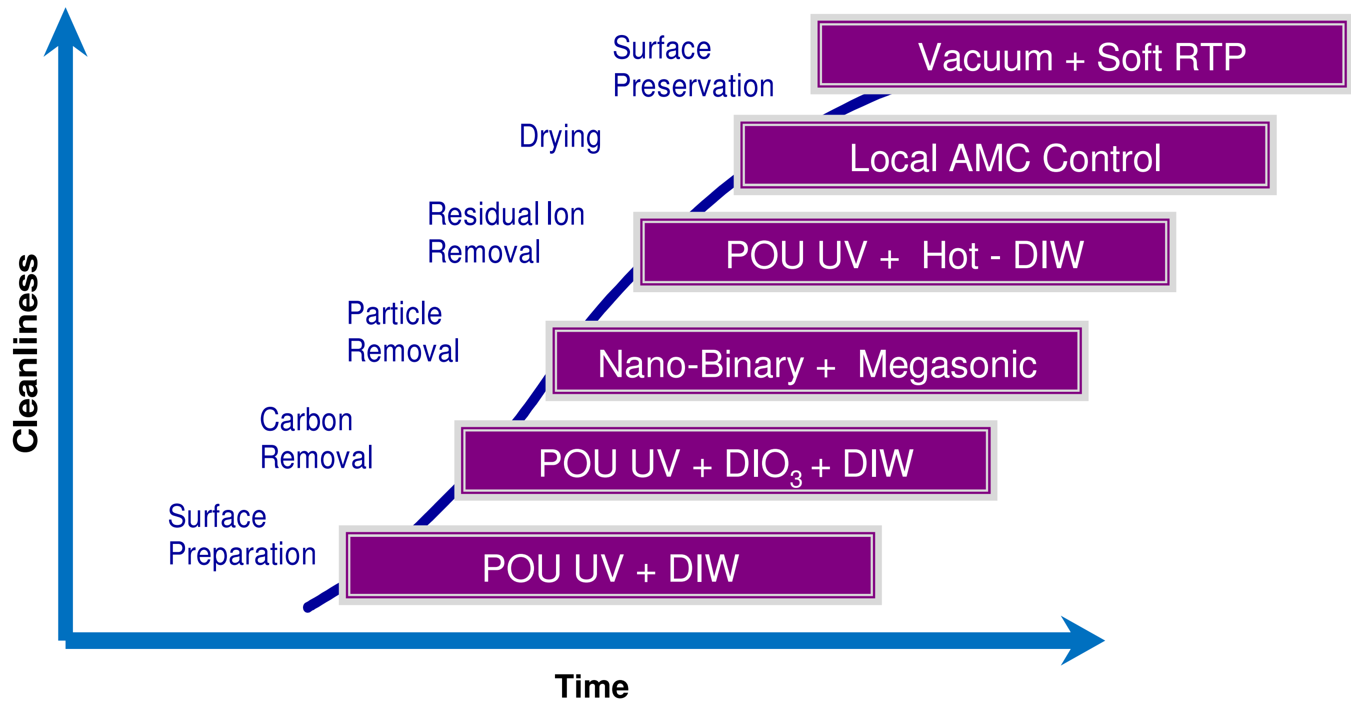
EUVL Mask Cleaning

EUVL Mask Cleaning POR Established at IMEC



SPM Free Cleaning!

Agenda

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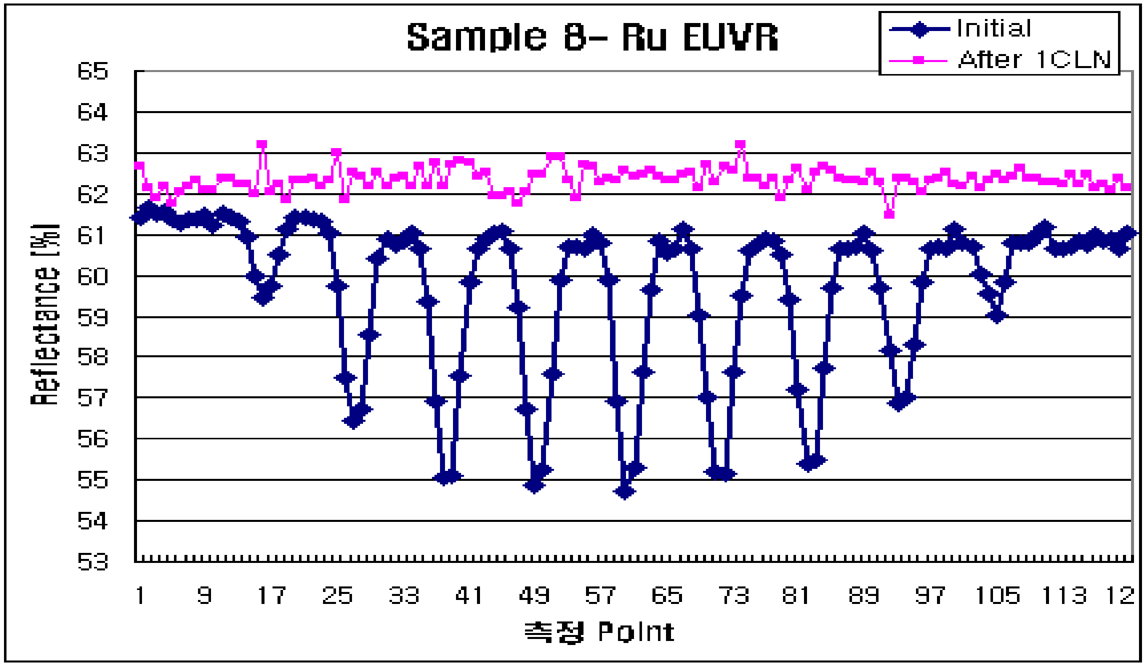
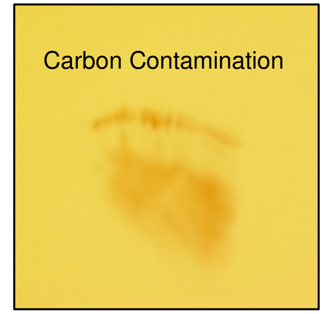
Experimental Cleaning Results

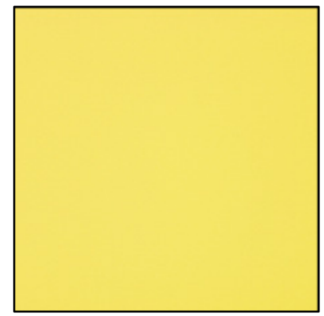
Carbon Removal Performance



Before Clean



After 1x POR Clean



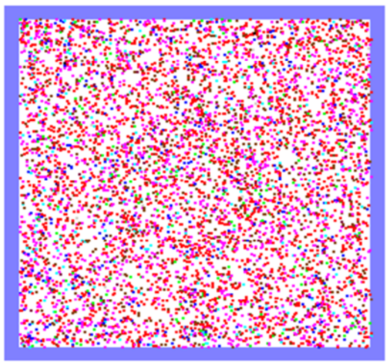
- A synchrotron was used to intentionally deposit carbon contamination
- Carbon contamination was *removed by 1x POR clean*

Data provided by SAMSUNG

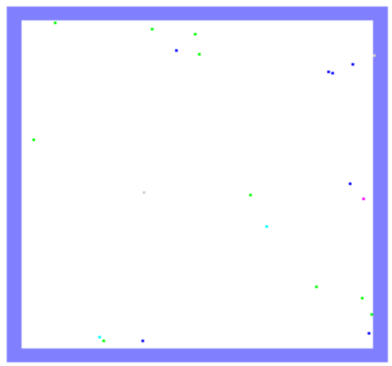
Experimental Cleaning Results

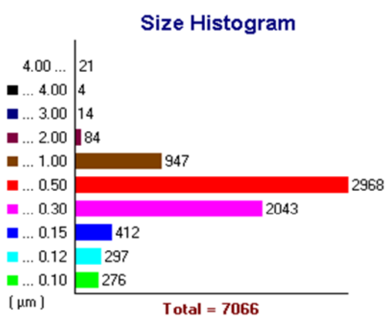
PRE Performance on SiN Particles

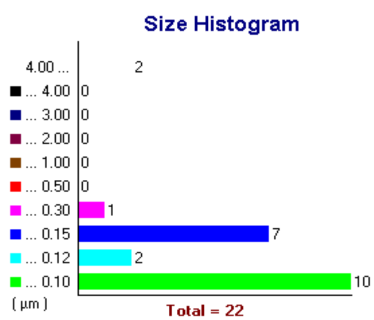
Before Clean



After 1x Clean





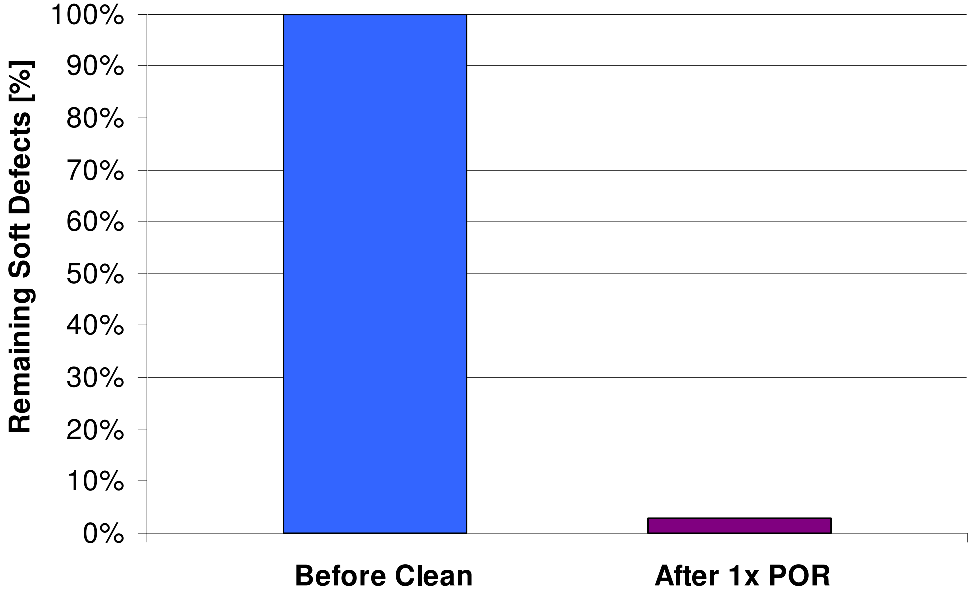


- POR applied to EUV blank
- Process yielded *>99 % PRE on first pass*
- Confirmed with further cleans

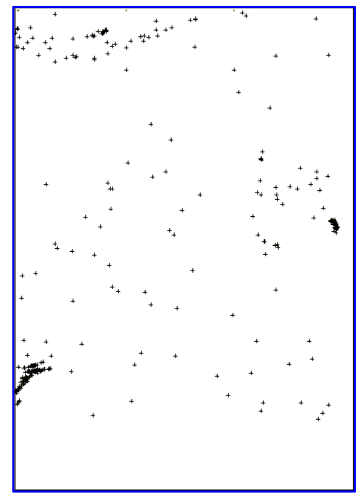
Data provided by SAMSUNG

Experimental Cleaning Results

PRE Performance on Natural Particle Contamination (IMEC Defect 32-2)

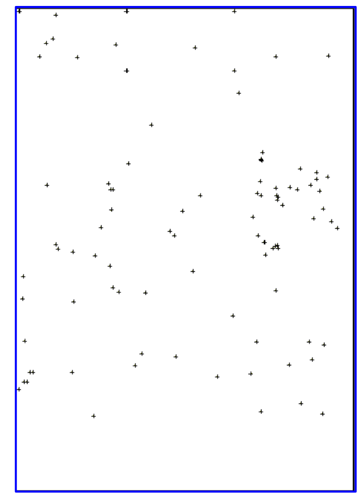


Before Clean



Soft & Hard Defects

After 1x POR Clean

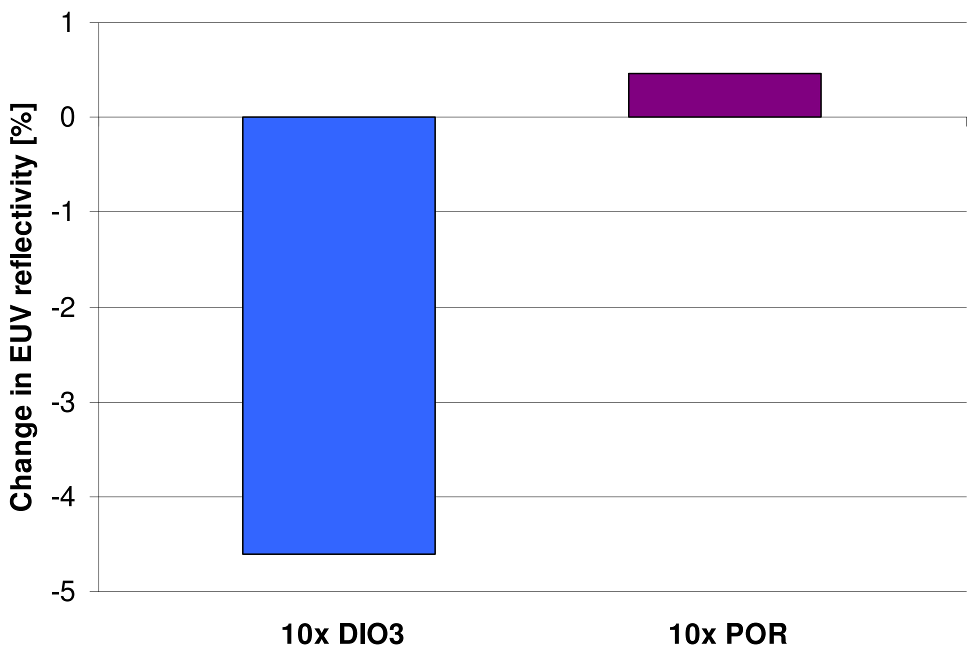


Hard Defects remain

- POR applied to EUV pattern mask
- Cleaning process yielded *>97 % PRE on first pass*
- *< 1 adder* per clean average (based on wafer defect analysis of repeat cleans)
- Remaining defects are non-removable in repeat cleaning and match typical level of absorber/blank/mask related hard defects
- *No hard defects added* (based on wafer defect analysis of repeat cleans)

Experimental Cleaning Results

Conventional DIO3 Cleaning vs. POR (Blank Vendor A)



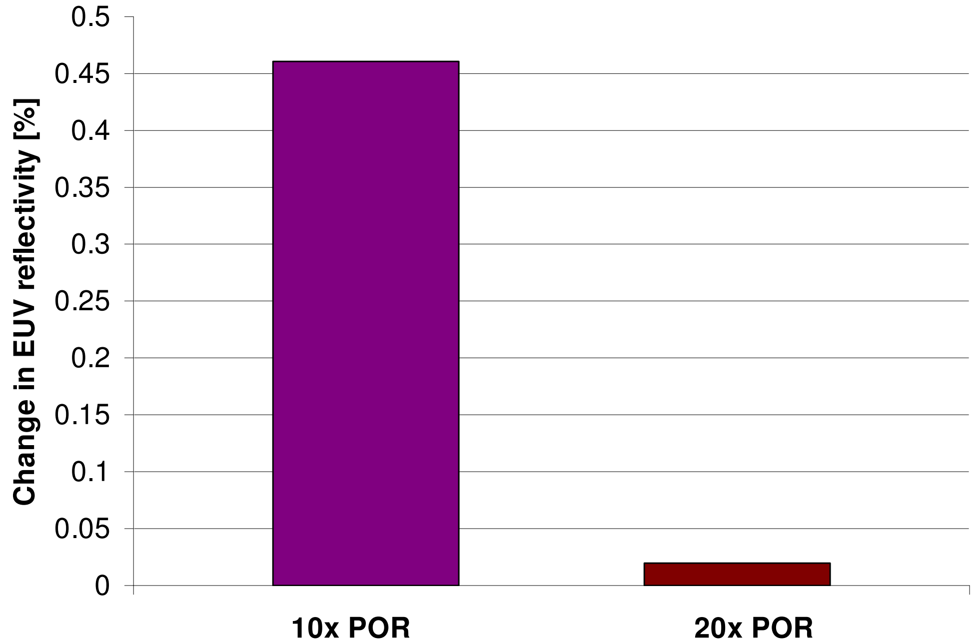
See also Poster: R. Lebert et al. „Contributions to EUV mask metrology infrastructure: Reflectometer, Blank Inspection and DPP+LPP EUV Sources“

- 10x Conventional DIO3 process caused substantial deterioration of EUV reflectivity. Magnitude suggests complete Ru removal and ML damage.
- 10x POR cleaning resulted in a *slight EUV reflectivity improvement*.

Experimental Cleaning Results

Understand. Align. Innovate. Develop.

EUV Reflectivity (Blank Vendor A)



Note reflectivity scale!

- *EUV reflectivity still slightly increased* even after 20x POR
- Slight reduction in EUV reflectivity between 10x and 20x POR may be due to:
  - Repeatability of metrology
  - Slight ML reflectivity change
  - Unequal rate of organic surface material accumulation

Experimental Cleaning Results

XPS Analysis (Blank Vendor A)

	C	RuO	Ru	Si	Mo	SiO	S	O
Virgin	17.69	9.25	22.81	11.12	0.71	3.91	1.4	33.1
10x POR	26.29	9.69	18.03	10.83	0.87	3.29	0	31

Values in %

	C	RuO	Ru	RuO+Ru
Virgin	0.33	0.66	1.63	2.29
10x POR	0.49	0.89	1.44	2.33

Values in nm

- XPS material analysis suggests only *minor changes in surface layer structure*
- XPS based material thickness modeling *confirms integrity of Ru capping layer*
- Acid-free POR shows *good Sulfur removal* capability

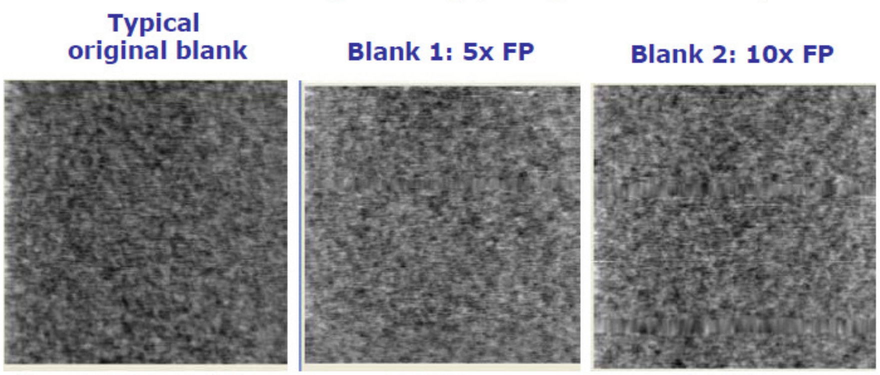
Note: Elevated Carbon signature on 10x cleaned sample may be due to difference in sample handling prior to XPS

Experimental Cleaning Results

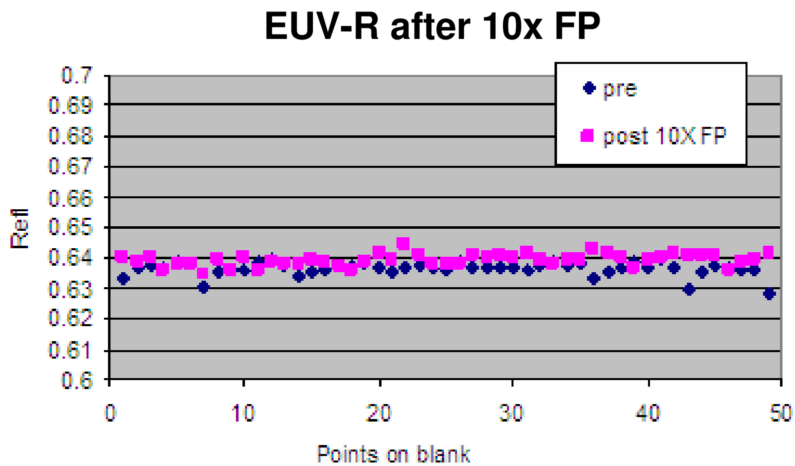
Understand. Align. Innovate. Develop.

EUV Reflectivity and AFM Surface Roughness (Vendor A)

- **Raw surface roughness (2μ x 2μ AFM scans)**



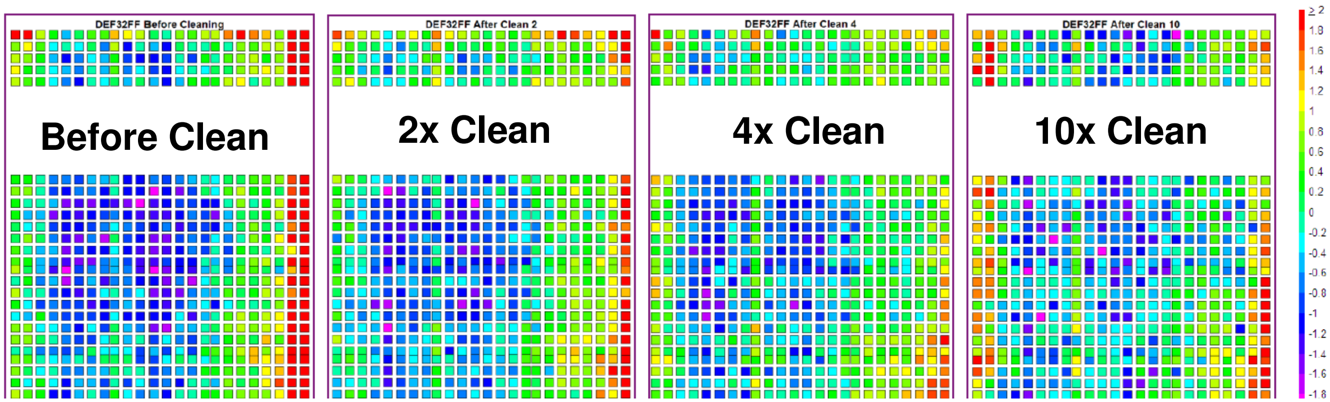
Raw RMS: 0.138nm 0.108nm 0.107nm

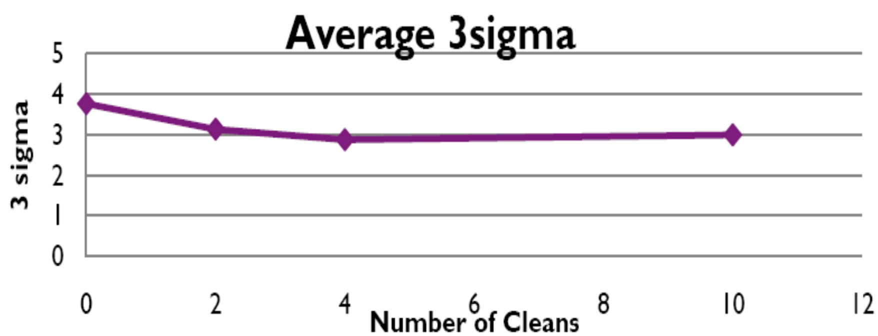


- *Slight improvement* in surface quality observed after *5x clean*
- *No degradation* of surface roughness observed throughout *10x clean*
- *Slightly higher* EUV reflectivity after *10x clean*

Experimental Cleaning Results

CD Uniformity Signature (Pattern EUV Mask on Blank Vendor B)

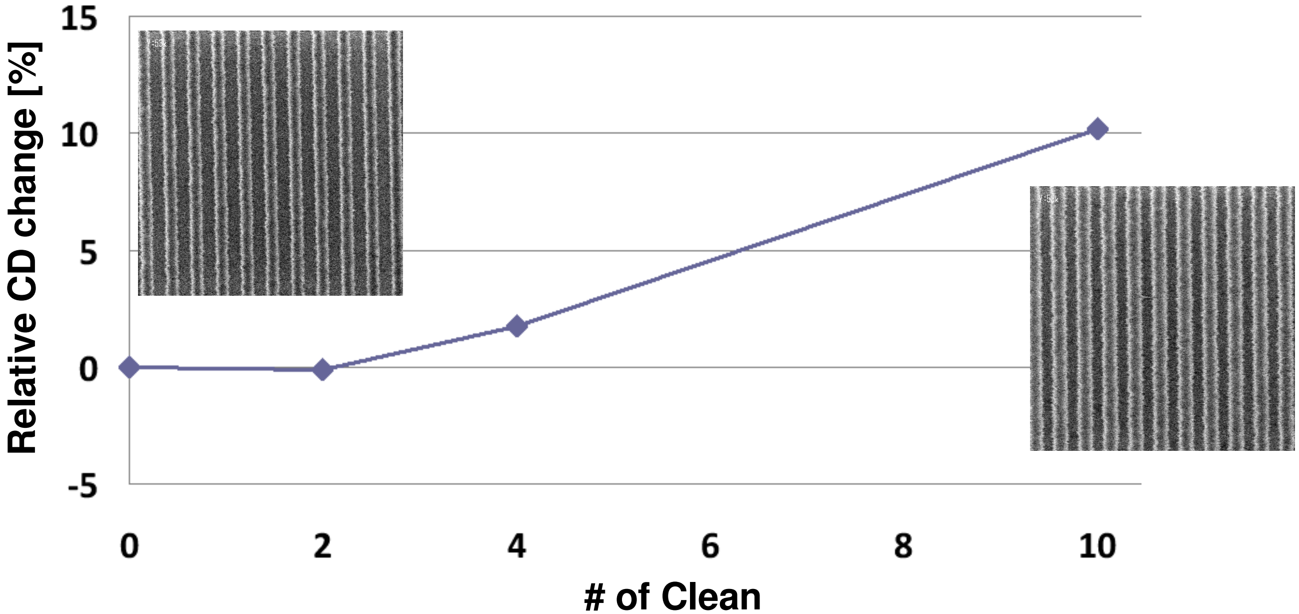




- *No significant change* in CD signature observed throughout *10x clean*
- CD uniformity improves slightly after first two cleans
- CD uniformity constant between clean 2 and clean 10

Experimental Cleaning Results

CD Mean (Pattern EUV Mask on Blank Vendor B)



- *No* change in CD mean up to *2x clean*
- *Slight* change in CD mean after *4x clean*
- *Dramatic* CD mean shift after *10x clean*

Note: 10% CD shift exceeds the predicted effects of complete Ru loss (ML damage?)

Experimental Cleaning Results

Potential Root Cause for CD Mean Shift After 10x Clean

- Partial damage or weakening of Ru through exposure to aggressive resist strip and cleaning during mask manufacturing
- Ru structure altered due to residual moisture on mask during EUV exposure
- Cleaning process conditions changed unnoticed
- Electrolytic erosion of Ru through surrounding TaBN absorber
- Difference in Ru structure of blanks provided by Vendor A vs. Vendor B

Further Investigation is needed!

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Summary

- EUV masks are contaminated during use (average of > 5 adders per week found when utilizing existing 193i infrastructure)
- Conventional DIO3 based cleaning quickly damages Ru capping
- Mask cleaning POR established at IMEC demonstrates improved results:
    - Complete removal of EUV induced Carbon with 1x clean
    - No detectable degradation in EUV reflectivity after 20x clean
    - High stability in ML structure (based on XPS)
    - No increase in surface roughness of Ru (based on AFM)
    - PRE > 97% for natural defects (handling, storage) and > 99% for SiN
    - Low particle adder rate (cleaning and ADT pod transfer)
    - No detectable feature damage after 10x clean
    - No significant CD uniformity shift after 10x clean
- Unusual CD mean shift on pattern mask requires further investigation!

Conclusions

- The useful lifetime of an EUV mask depends on:
  - Durability of surface layers (especially capping)
  - Choice of cleaning methods
  - Frequency of cleaning (MTBC - Mean Time Between Cleans)
  - Acceptable ML performance loss
- Optical properties of ML can be maintained if proper cleaning techniques are employed (*> 50x clean cycles within reach based on current results!).*
- Blank material may have significant impact on surface layer durability (further studies are needed)
- Other factors, such as mask manufacturing techniques and EUV exposure conditions (e.g. residual moisture on mask surface) need further investigation
- Pod-in-pod infrastructure urgently needed for:
  - Mask shop backend of line
  - Shipping between mask shop and fab
  - In-fab Storage
  - In-fab transfer (e.g. between Storage/Clean/Inspection and Scanner)

Acknowledgement

- Daehyuk Kang, Hanshin Lee and Jinhong Park of Samsung for data and metrology support
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- Rainer Lebert of Bruker for EUV reflectivity metrology and data analysis
- CATRENE EXEPT for its support of EUVL technology development throughout Europe

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Our customers' success is our responsibility